SEISMIC SEQUENCE STRATIGRAPHIC ANALYSIS OF THE TERRESTRIAL PART OF DOLNA KAMCHIYA SEDIMENTARY BASIN

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ABSTRACT. Dolna Kamchiya sedimentary basin is the longest studied petroleum zone in Bulgaria. It has been the focus of petroleum geologists for 67 years. Despite the numerous studies mainly on the terrestrial part of Dolna Kamchiya sedimentary basin, there are still unresolved tasks related to its lithofacial and stratigraphic variability. Dolna Kamchiya sedimentary basin is longitudinally oriented (subparallel), filled predominantly by terrigenous Paleocene-Neogene sediments with considerable thickness, and an asymmetrical transverse and longitudinal profile. More than 2/3 of the territorial scope of the basin is located in the Black Sea area, only its westernmost periphery is developed on a relatively small terrestrial territory. Northern, western and southern borders are well-defined and traceable to this part of the sedimentary basin. The main goal of this study is to carry out a seismic-sequence stratigraphic analysis of the terrestrial part of Dolna Kamchiya sedimentary basin.The main tasks in this study are summarized as follows: identifying sedimentary sequences by seismic data as well as recognition and delineation of their systems tracts. Solving the assigned tasks is based on data from 48 (prospecting and exploratory) wells and 15 migrated 2D seismic profiles in the basin, and is achieved by the application of seismostratigraphic analysis supplemented by paleotectonic and paleogeographic analysis. The application of the seismostratigraphic methods contributes to obtaining qualitatively new information about the deep geological structure and the geological development as well as increasing the efficiency of oil and gas prospecting. The identification of sedimentary sequences by seismic data allows more accurate prediction of sedimentary environments and lithofacies. This in turn, improves the forecasting of reservoirs, seals, source rocks and hydrocarbon migration pathways. The seismostratigraphic analysis of the sedimentary complex in Dolna Kamchiya sedimentary basin shows the development the I-type sequences formed within the stratigraphic cycles of the 2nd and 3rd order. The sequences have terrigenous, predominantly clayey-sandy composition.

Keywords: accumulations seismic-sequence stratigraphic analysis, Dolna Kamchiya sedimentary basin.

СЕИЗМИЧЕН СЕКВЕТНО-СТРАТИГРАФСКИ АНАЛИЗ НА СУХОЗЕМНАТА ЧАСТ ОТ ДОЛНОКАМЧИЙСКИЯ СЕДИМЕНТЕН БАСЕЙН

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РЕЗЮМЕ. Долнокамчийският седиментен басейн е най-дълго проучваната нефтогазоносна зона в България. Вече 67 години той е във фокуса на петролните геолози. Независимо от многобройните изследвания, основно в участъка на сушата от Долнокамчийския басейн, остават все още не малко нерешени задачи, свързани с неговите литофациална и стратиграфска изменчивост. Долнокамчийският седиментен басейн е надлъжно (субпаралелно) ориентиран, запълнен с палеоцен-неогенски, предимно теригенни седименти със значителна дебелина, и има асиметричен напречен и надлъжен профил. Повече от 2/3 от териториалния обхват на басейна са разположени в Черноморската акватория, като само най-западната му периферия е развита на сушата върху сравнително малка територия. На този участък от басейна дълбочинните му северна, западна и южна граници са проследени и изяснени най-добре. Главната цел на изследването е провеждането на сеизмичен секвентно-стратиграфски анализ на сухоземната част от разреза на басейна. Основните задачи в настоящата работа се свеждат до: идентифициране на седиментните секвенции по сеизмични данни и разпознаване и очертаване на изграждащите ги трактови единици. Решаването на поставените задачи се базира на данни от 48 търсещо-проучвателни сондажи и 15 мигрирани 2D сеизмични профили в басейна и се постига с прилагането на сеизмостратиграфския анализ, допълнен с палеотектонски и палеогеографски анализ. Прилагането на методите на сеизмостратиграфията допринася за получаването на качествено нова информация за дълбочинния геоложки строеж и геоложкото развитие, както и за повишаване на ефективността на търсещите проучвания за нефт и газ. Идентифицирането на седиментните секвенции по сеизмични данни дава възможност за по-точно предсказване на седиментните обстановки и литофациеси. Това от своя страна позволява да се подобри прогнозирането на резервоари, покривки, нефтомайчини скали, капани и пътищата за въглеводородна миграция. Сеизмостратиграфският анализ на седиментния комплекс в Долнокамчийския седиментен басейн показва развитието на секвенции от I тип, формирани в рамките на стратиграфски цикли от II и III порядък. Секвенциите се отличават с теригенен, доминиращо глинесто-песъчлив състав.

***Ключови думи**: сеизмичен, секвентно-стратиграфски анализ, Долнокамчийски седиментен басейн*

Introduction

Dolna Kamchiya sedimentary basin is the longest studied petroleum zone in Bulgaria (Fig. 1). It has been the focus of petroleum geologists for 67 years. Despite the numerous studies mainly on the terrestrial part of Dolna Kamchiya sedimentary basin, there are still unresolved tasks related to its lithofacial and stratigraphic variability. Until now, seismostratigraphic analysis has only been applied to the offshore part of the basin, the results of which are presented in several publications (Georgiev et al., 2004; Dimitrov and Georgiev, 2005; Dimitrov, 2007; Dimitrov , 2008; Dimitrov and Georgiev, 2011). The main goal of this study is to carry out a seismic-sequence stratigraphic analysis of the terrestrial part of Dolna Kamchiya sedimentary basin. The main tasks in this study are summarized as follows: identifying sedimentary sequences by seismic data as well as recognizing and delineating of their systems tracts. The application of the seismostratigraphic methods contributes to obtaining qualitatively new information about the deep geological structure and the geological development as well as increasing the efficiency of oil and gas prospecting. The identification of sedimentary sequences by seismic data allows more accurate prediction of sedimentary environments and lithofacies. This in turn, improves the forecasting of reservoirs, seals, source rocks and hydrocarbon migration pathways in the section of Dolna Kamchiya sedimentary basin.

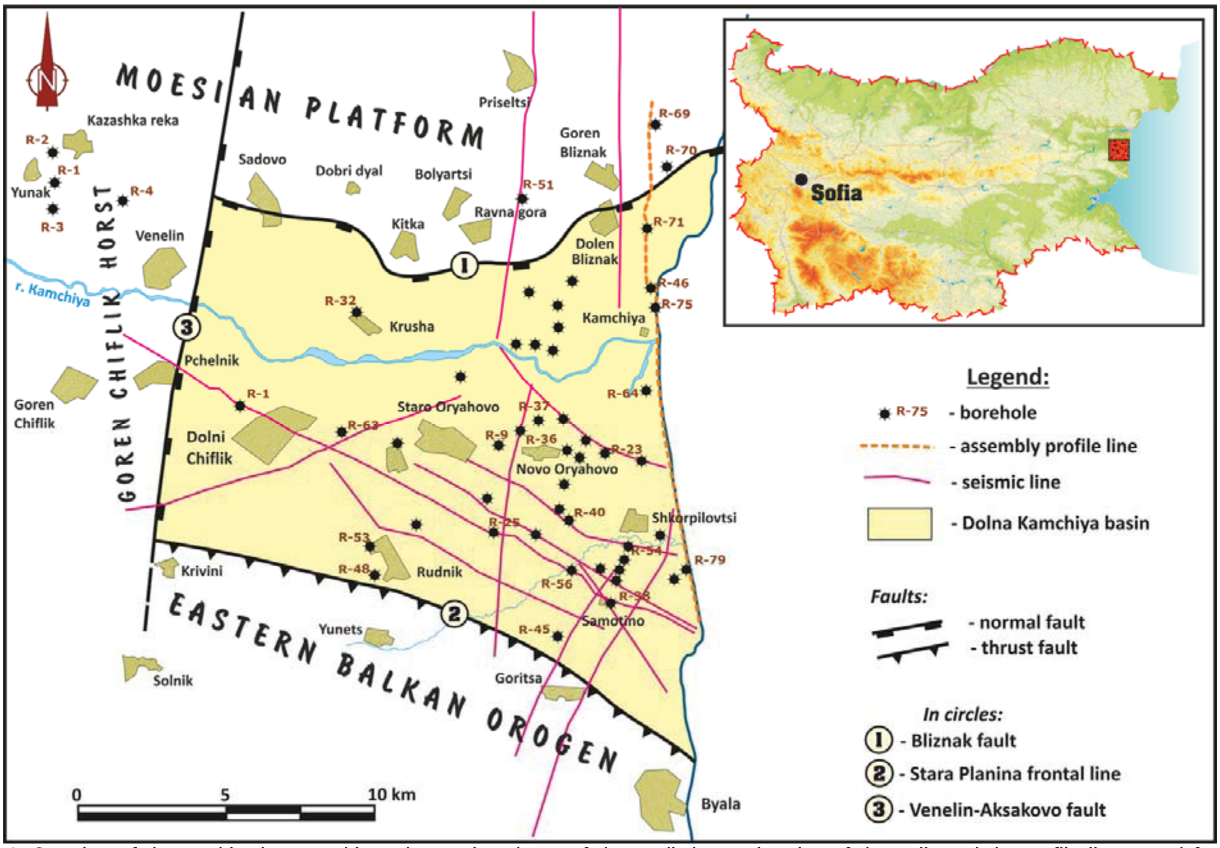

Fig. 1. Overview of the combined geographic and tectonic scheme of the studied area, location of the wells and the profile lines, used for the seismostratigraphic analysis

Materials and methods

For identifying, within Dolna Kamchiya sedimentary basin, seismic-sequence boundaries, maximum flooding surfaces and analyzing sequences with their systems tracts are used data from 48 wells (prospecting and exploratory) and 15 migrated 2D seismic profiles (Fig. 1). Interpretation and correlation of the seismic boundaries with lithostratigraphic units, separated during drilling, are made by the detailed analysis of the sections composite well logs. The quality of some profiles is not the best, but still available material allowed to be made sufficiently good interpretation. The approach used for the purpose of the study is entirely based on the concept of sedimentary sequences (Sloss, 1963; Vail et al., 1977; Van Wagoner and Posamentier, 1988; Van Wagoner et. all., 1990) and seismostratigraphic analysis (Vail et al. 1977, 1991; Bally-ed., 1987; Miall, 1996).

Geological Framework

Tectonics

Dolna Kamchiya sedimentary basin is longitudinally oriented (subparallel), filled predominantly by terrigenous Paleocene-Neogene sediments with considerable thickness, and an asymmetrical transverse and longitudinal profile. More than 2/3 of the territorial scope of the basin is located in the Black Sea area, only its westernmost periphery is developed on a relatively small terrestrial territory. Northern, western and southern borders are well-defined and traceable to this part of the sedimentary basin. (Fig. 1). The northern border with Moesian platform is marked by Bliznak fault, while to the south by Stara Planina frontal line. Sub-meridional Gornochiflishki narrow horst restricts the development of Dolna Kamchiya sedimentary basin to the west along Venelin – Aksakovo fault. The spatial lithofacies distribution in Dolna Kamchiya sedimentary basin and its geometry decisively confirm its development as a foreland basin (Dimitrov, 2012), superimposed on the structures of the Fore Balkan zone and the southern flank of the Moesian platform as a result of intensive folding and thrusting of the Balkanides system throughout the Illyrian tectogenesis. Dolna Kamchyia sedimentary basin opens to the east and extends its width from 10-15 km to the west to 80 km and more in the eastern part. The total thickness of the sedimentary complex, filling Dolna Kamchiya basin, exceeds 5 km (Georgiev, 1996).

Lithostratigraphy

Figure 2 shows the spatial-temporal relationships of lithostratigraphic units involved in the substrate and the filling of Dolna Kamchiya basin. The sedimentary section at the base of the basin is presented by Middle Eocene conglomerates and sandstones of Dvoinitsa formation (Dzhuranov, Pimpirev,

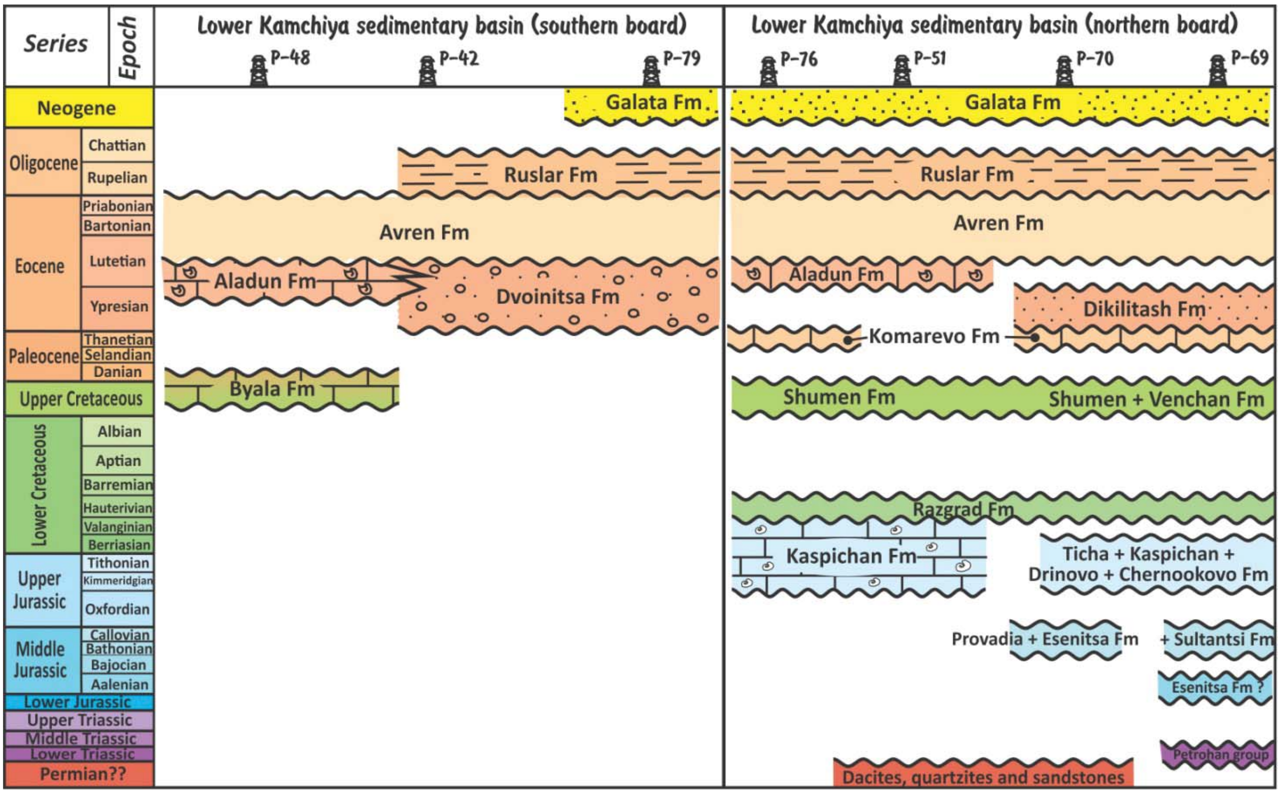

Fig. 2. Lithostratigraphic scheme of the filling and the basement substructure of Dolna Kamchiya sedimentary basin by drilling data

1989), which have been penetrated both onshore and offshore by several wells. The upper-Eocene sediments of Avren formation (Gochev, 1933) are typified by sandstones at the base and alternation of marls, sandstones, siltstones and sandstones with detritus at the top. Ruslar formation (Aladzhova-Hrischeva, 1991) starts with transgressive sandstones at the base, passing up into marine clays. The middle Miocene (Chokrakian) sediments of Galata formation (Koyumdzhieva, Popov, 1986) unconformably overlie the Oligocene sediments and together form a common sedimentary complex.

The basement substructure on the northern and southern board of the basin differs from its typical formations. In the northern part, it is represented by Paleozoic (Permian?) rocks (dacites, quartzites and sandstones), which are penetrated by R-51 Ravna Gora and R-70 Bliznatsi wells. Unfortunately, these deposits are not stratified because of the absence of fossils and lack of their basement substructure. The lack of fauna does not give a chance to determine the exact age of rocks. Mesozoic section in the northern board of Dolna Kamchiya basin is presented by Lower Triassic sandstones.

Seismic-Sequence Stratigraphic Analysis

Seismic Sequences

Firstly, in order to be identified and spatially traced seismic sequences, the seismic sequence boundaries were traced, which are substantially unconformities. The significance of the unconformities is expressed in the fact that they indicate a fundamental change in the environment of the basin – from sedimentation to lack of replenishment or erosion, related to significant tectonic or eustatic changes.

Two types of unconformities are traced (angular and parallel) in the analysis of the 15 migrated 2D seismic profiles from the terrestrial part of the Dolna Kamchiya sedimentary basin (Fig. 3). The angular unconformities are traced in the southern board of the basin and they are related to the occurrence of folding and thrusting during the Illyrian (Middle Eocene), the Pyrenean (Late Eocene) and the Savian (Late Oligocene) alpine folding phases. They are marked by the presence of erosional truncation of older sediments, which are covered by younger ones with a different angle of onlap and downlap. To the northern direction (to the depocenter of the basin) the surfaces gradually pass to the parallel unconformities. As a result of the analysis, three sequence boundaries are marked and traced, which are proved by the type of discontinuity of the reflections under and over them. The sequence boundaries outline three seismic sequences, which are essentially sedimentary complexes, marked on the seismic sections (Fig. 3). These three sequences are involved in filling the terrestrial part of the basin and are conditionally numbered from 1 to 3 as follows: 1 - Miocene; 2 - Oligocene; And 3 – Upper Eocene. Spatial development, geometry, and sequence relationships are shown on a combined seismic cross-section (Fig. 3).

The Upper Eocene sequence (indicated by the number 3) is restricted by type 1 unconformity boundaries, which define it as a type 1 sequence boundary. Its lower boundary is the Illyrian unconformity marking the beginning of the development of the Dolna Kamchiya sedimentary basin, and the upper boundary is the unconformity surface related to the occurrence

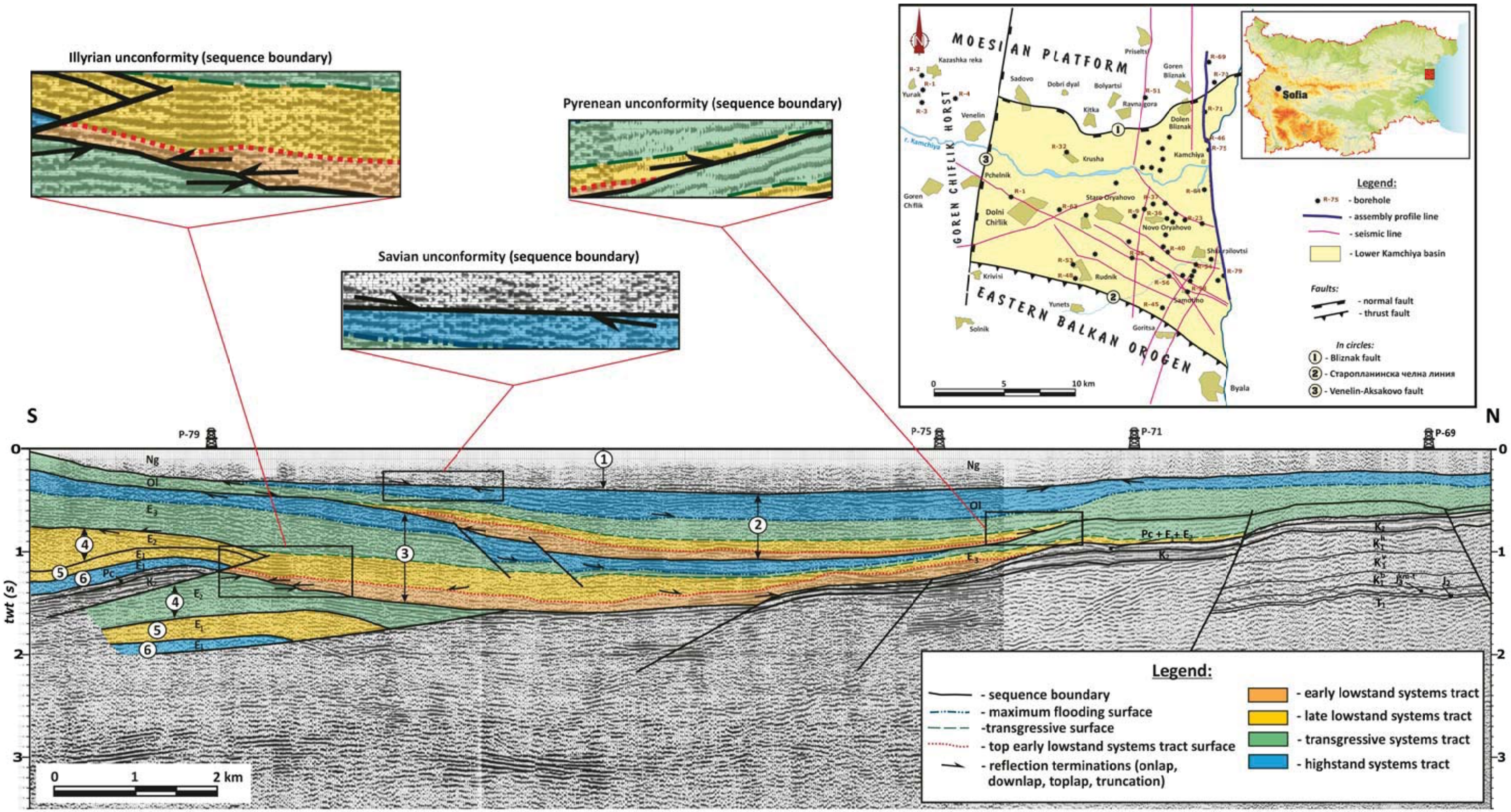

Fig. 3. A combined seismic profile line with south-north direction showing separated and outlined seismic sequences and systems tracts. The identified sequence boundaries are unconformity surfaces, and the internal seismic systems tracts are maximum flooding surfaces. In the circles with numbers from 1 to 3, the sequences of the section of the Dolna Kamchiya sedimentary basin are marked, and the numbers from 4 to 6 - those that construct the basement substructure in the southern part of the basin.

of the Pyrenean folding phase. The sedimentation of the sequence is within a sedimentary cycle of about 3.3 million years, which determines it as a stratigraphic unit of the third order.

The Oligocene sequence (indicated by the number 2) is traced by type 1 unconformity boundaries and because of that it is added to type 1 sequence boundaries. The role of its lower boundary performs the Pyrenean unconformity, and the upper boundary is the unconformity surface associated with the occurrence of the Savian folding phase. The sediments involved in the construction of the sequence are formed in the interval of a sedimentary cycle of about 10.8 million years, which determines it as a stratigraphic unit of the second order.

The Miocene sequence (indicated by the number 1) is with the smallest thickness in the scope of the studied part of the terrestrial part of the Dolna Kamchiya sedimentary basin. It is extremely difficult to analyze and interpret its internal construction and this is the reason to indicate confidently only its lower boundary, which is the result of the Savian folding phase. It is divided in detail in the offshore part of the basin (Georgiev et al., 2004, Dimitrov and Georgiev, 2005, Dimitrov , 2007, Dimitrov , 2008, Dimitrov and Georgiev, 2011). It is identified as a type 1 sequence, restricted between the Savian unconformity and the Messinian unconformity. Its formation lasted about 14 million years in a stratigraphic cycle of the second order.

In the southern part of the basin substrate, three additional sequences are separated and are conditionally numbered from 4 to 6 (Fig. 3). These are: the Middle Eocene sequence (indicated by the number 4) and two sequences with Lower Eocene age (indicated by the numbers 5 and 6). The location of the traced sequence boundaries is fully compliant with the R-79 well in which, on the basis of SP log, there is convincing data for their marking. Unfortunately, on the interpreted seismic profiles, data of their separation and tracing has not been seen. This is explained by the complex situation resulting from the active tectonics during the Illyrian folding phase. The sedimentary complexes are removed from their initial formation position, as they have undergone folding and thrusting and it is extremely difficult to comment what part from the paleobasin they represent.

Seismic Systems Tracts

In interpreting the seismic sections from the studied area, the development of three systems tracts is well established in the Upper Eocene and the Oligocene sequences, described in the classic model of Vail et al. (1977).

The Upper Eocene sequence starts with the early lowstand systems tract, which is developed in the central part of the basin. Its lower boundary is the unconformity surface, and the upper boundary is the first flooding surface (Fig. 3). It is characterized on the seismic sections with wavy and hummocky configurations, which are interpreted as basin floor fans and slope fan complexes. Over the early lowstand systems tract is formed the late lowstand systems tract. Its upper boundary is the next significant maximum flooding surface – transgressive. The seismic sections reveal the characteristic wedge geometry and seismic reflections ending with downlap to the top of the basin and slope fans, which gives a reason to interpret that this tract is associated with the formation of a wedge-prograding complex. The transgressive systems tract lies between two significant flooding surfaces - the transgressive surface at the bottom and the maximum flooding surface at the top. The maximum flooding surface is marked by a downlap seismic configuration. The transgressive systems tract is widespread as the smallest thicknesses are recorded in the central part of the basin. The highstand systems tract is marked at the top of the section, whose upper boundary is the Pyrenean unconformity. The characteristic seismic reflections (truncation type) are clearly noted below it.

In the Oligocene sequence, the lowstand systems tract is also represented by its two distinct parts - the early lowstand systems tract and the late lowstand systems tract (Fig. 3). The early lowstand systems tract is restricted by the unconformity surface at the bottom (the Pyrenean unconformity) and the first significant flooding surface at the top. The floor fan fans and the slope fan complexes are clearly identified on the basis of the seismic sections. The late lowstand systems tract covers the early one, its upper boundary is the transgressive surface and, according to the seismic reflections, it can be interpreted as the wedge-prograding complex. After that, it follows the development of the transgressive systems tract, whose lower boundary, in the majority of the basin, is transgressive, and the smaller one is the sequence boundary. The upper boundary of the transgressive systems tract is the maximum flooding surface. The highstand systems tract is marked at the top of the section, whose upper boundary is the Savian unconformity. The characteristic seismic reflections (truncation type) are clearly noted below it.

Well Log Sequence

The separated well log sequences with their system tracts in the terrestrial part of the section of the Dolna Kamchiya sedimentary basin are shown in Figures 4, 5 and 6. The well diagram of P-79, which is located in the southern part of the basin, is applied to fragments of the combined seismic section (Figs. 1 and 3). The geometry of spontaneous potential and resistivity logs is analyzed along the well section. Each of the situations is adapted to the theoretical model of Mitchum, et al. (1993).

The trends in the geometric shape of the spontaneous potential log from 50 m to 318 m, for the Miocene sequence (indicated by 1), indicate the development of the highstand systems tract (Fig. 4). The medium-grained sandstones, siltstones and clayey sediments are located at the bottom of the tract, and upward the sediments are found in more coarse-grained facies. The model of PS log has a funnel shape, which is interpreted as a sedimentary section formed under conditions of progradation in the basin.

The Oligocene sequence (indicated by 2) in the well section of R-79 is represented only by the transgressive systems tract (Fig. 5). At a depth of 319 m to 407 m, the spontaneous potential log has a pronounced bell–shaped curve that is interpreted by a lithological change from the bottom to the top. The coarse-grained terrigenous sediments are located at the bottom of the section, and upward they pass into more clayey sediments, suggesting the formation of a typical retrograde model in this part of the basin.

Two systems tracts are separated by the spontaneous potential log of P-79, involved in the construction of the Upper Eocene sequence (indicated by 3) – the transgressive systems tract (from 458 m to 1038 m) and the high stand systems tract (from 407 m to 458 m) (Fig. 5). The boundary between two systems tracts is very clearly marked because it reflects the presence of a maximum flooding surface. Above it, the model of a logging curve is with the funnel shape indicating of progradating architecture, while the bell–shaped curve below it shows a retrograde model of the sedimentary section. The R-79 well also reveals the substrate section of the Dolna Kamchiya basin (Fig. 6). Firstly, for the Middle Eocene sequence (indicated by 4), in the depth interval 1039 m - 1365 m, according to the geometry of the spontaneous potential log, which is the bell-shaped, the lowstand systems tract (the wedge–progradating complex) is interpreted. Two sequences are separated by the logging curve in the Lower Eocene section (indicated by 5 and 6). The first, according to the logging curve, is interpreted as the wedge–progradating complex from the late lowstand systems tract (from 1365 m to 1955 m). The breccia–conglomerates are found at the bottom, which gradually begin upward to alternate with more coarse-grained sand-

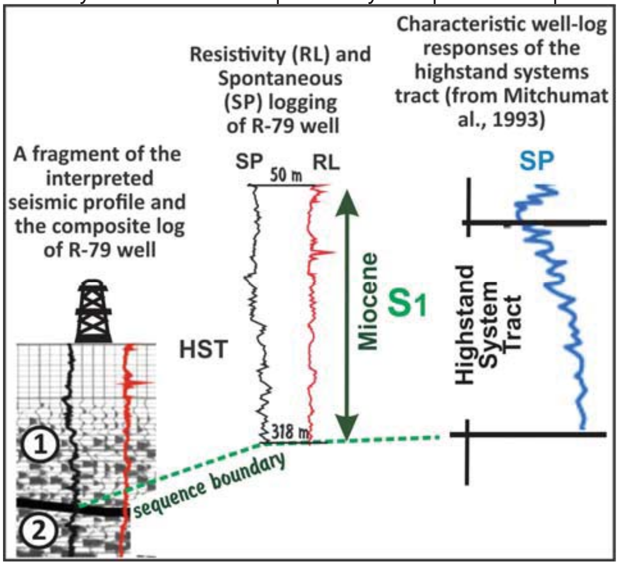

Fig. 4. The Miocene sequence (indicated by 1), separated on basis of the spontaneous potential log of R-79 well

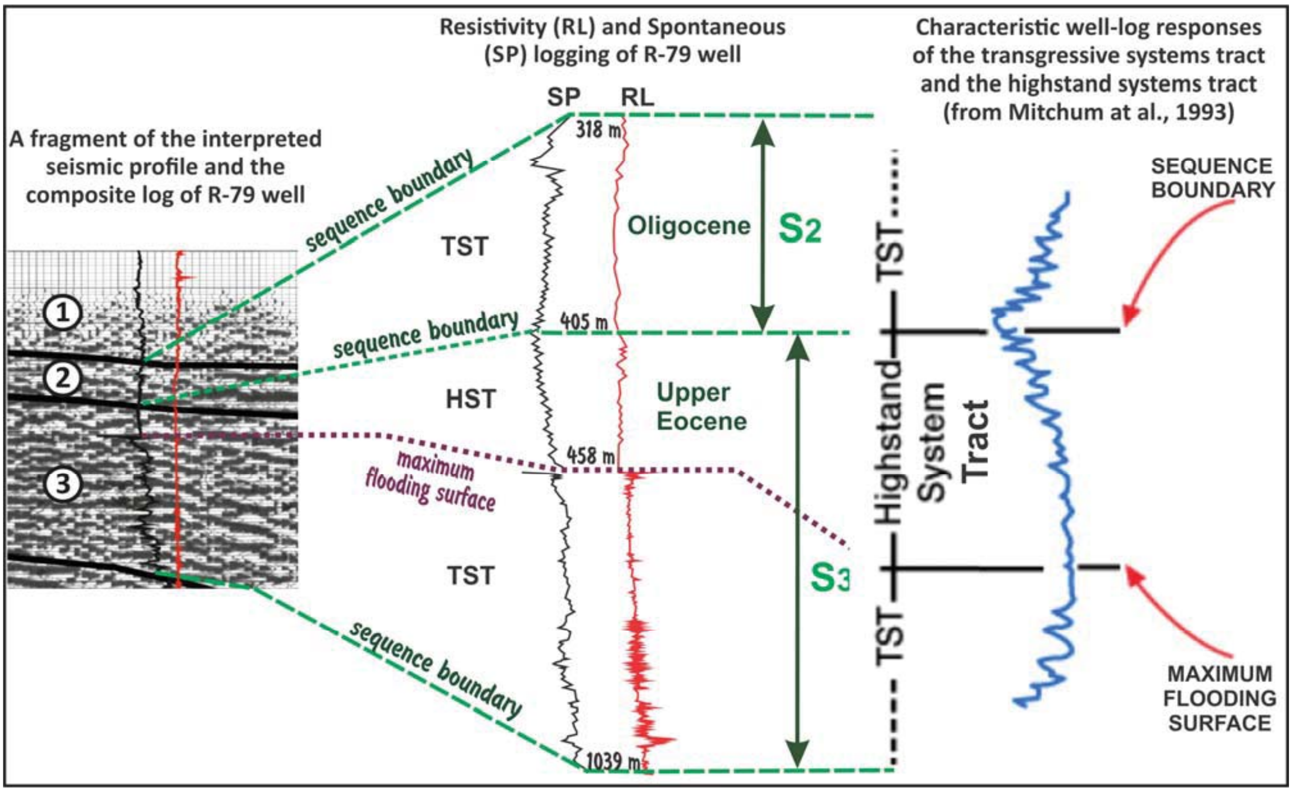

Fig. 5. The Oligocene (indicated by 2) and the Upper Eocene (indicated by 3) well log sequences, separated on basis of the spontaneous potential log of R-79 well

stones in the beginning of the tract, and more fine-grained sandstones at the top. The second, the lower Eocene sequence (indicated by 6), which is the depth interval from 1955 m to 2367 m, according to the model of the spontaneous potential log, is interpreted as the high stand systems tract. According to the well table of R-79, the sedimentary section is defined in the interval from 2367 m to the bottom hole of the well (3490 m) with the lower Eocene-Paleocene age, which is questionable. In our view, there is really a Paleocene section at the top, as evidenced by the carbonate sediments, but from 2407 m to the bottom hole of the well, the logging curve does not repeat any elements separated by two lower Eocene sequences. The typical breccia – conglomerates are absent in the sequence 5, and the characteristic argillites in the sequence 6. This fact, as well as the interpretation of the combined seismic section, gives us the reason to believe that this part of the section is with the Middle Eocene age, which is revealed under the thrust sheet, including the sediments with the lower Eocene, Paleocene and Upper Cretaceous age. Due to the lack of serious and accurate dating data, this part of the section is not added to any of separated sequences of the basin substrate.

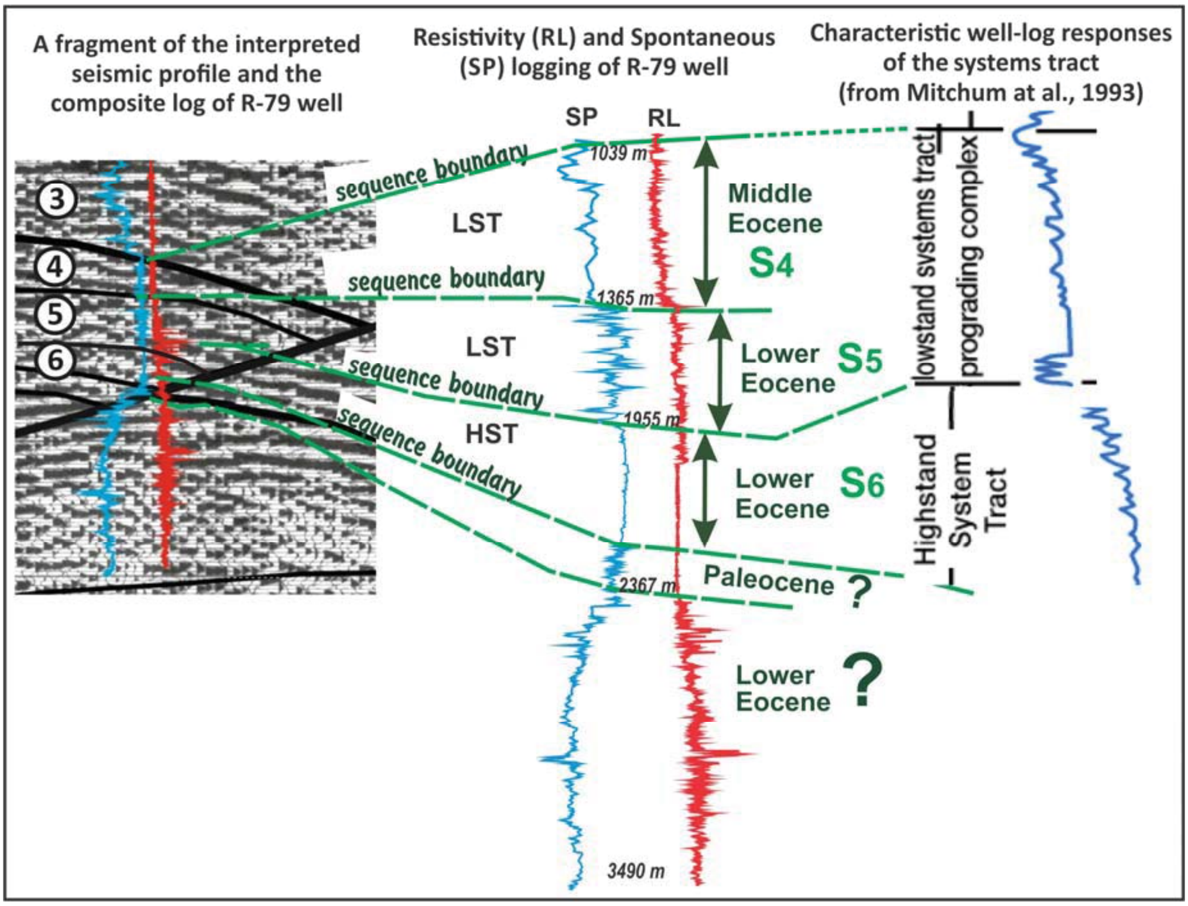

Fig. 6. The Middle Eocene (indicated by 4) and two Lower Eocene (indicated by 5 and 6) well log sequences, separated on the basis of the spontaneous potential log of R-79 well

Conclusion

The conducted seismostratigraphic study for the terrestrial part of the Dolna Kamchiya sedimentary basin gives the reason to make several important conclusions and put some tasks for future research.

Three unconformity surfaces are separated and traced by seismic wave fields in the basin section and they are accepted as basic seismic reflecting boundaries. The geometry of discontinuity of the seismic reflections under and over them, gives the reason for their identification as sequence boundaries. They outline three seismic sequences – the Upper Eocene, Oligocene and Miocene.

The Miocene and Oligocene sequences are separated on the seismic sections as well as correlating of logging diagrams, and they are defined as sequences of type 1, formed within a second-order stratigraphic cycle (10-100 million years), while the upper Eocene sequence is defined as a sequence of type 1, formed in the interval of a third order stratigraphic cycle (1-10 million years).

The seismic systems tracts, constructing sequences, are identified on the basis of recognizing and tracing secondary reflection surfaces (flooding surfaces between the early and the late low stand systems tract, transgressive surfaces and maximum flooding surfaces).

Another three sequences are separated by the methodology of well log sequence in the basin substrate – the Middle Eocene and two lower Eocene sequences, which are very difficult to analyze on the seismic sections due to the complicated geological environment in which they are located.

After conducting the study, a lot of unresolved issues remain that may be the subject of future exploration in the terrestrial part of the basin. The work should be continued with seismic facies analysis and tracing eustatic sea-level change, which will give the opportunity to perform forecast evaluation of the natural reservoirs and traps in connection with hydrocarbon prospect in this part of the basin.

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